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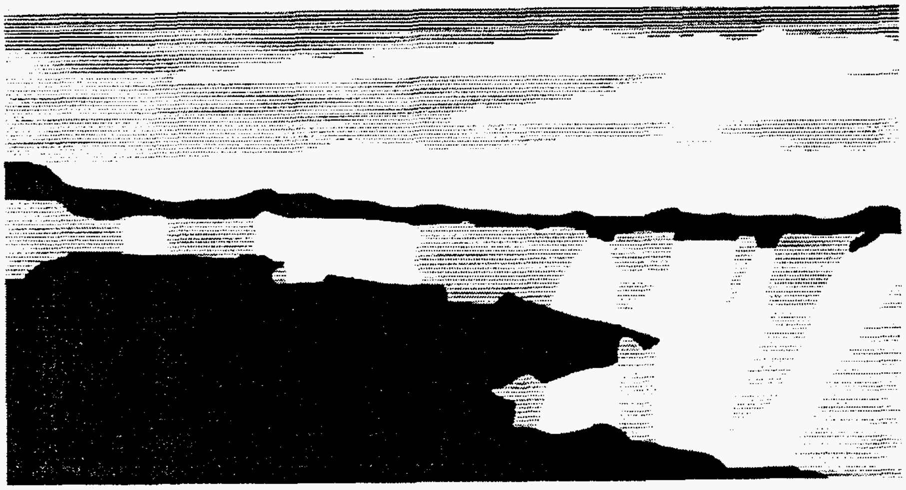

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Determination of the Nuclear Induced Electrical Conductivity of ^{3}He for Magnetohydrodynamic Energy Conversion

Leo Bitteker*, Jay Scheuer**, and Steven Howe

Abstract

This is the final report for a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The continual need for more efficient, high-output energy conversion techniques has renewed interest in nuclear-driven magnetohydrodynamic (MHD) energy conversion. To provide the fundamental knowledge required to evaluate the potential value of this concept, a one-year project aimed at measuring the nuclear-induced electrical conductivity of a ^{3}He/^{4}He gas mixture under thermodynamic conditions consistent with the MHD flow conditions was carried out. The range of bulk gas conditions to be considered were: pressure = 0.1 to 3800 Torr and temperature = 300 to 1500 K. The maximum neutron flux to be considered was 10^{16}/cm^{2}sec. The range of parameters considered surpassed previous experiments in all aspects.

1. Background and Research Objectives

The concept of nuclear-driven magnetohydrodynamic (MHD) energy conversion utilizes the interaction of the neutron flux of a nuclear reactor with a neutron-absorbing isotope in a MHD flow to enhance the electrical conductivity and hence, power output. The neutron absorbing species of interest to this project is ^{3}He.

The absorption of thermal neutrons by ^{3}He results in the production of a proton, triton, and 760 keV of kinetic energy. The kinetic energy of the proton and triton is transferred to the background gas by collisions, which result in ionization and excitation of the bulk gas. On the order of 10^4 ionizations occur per neutron absorbed. These ionization processes result in the production of a free electron population, which enhances the electrical conductivity of the gas. The degree of conductivity enhancement is determined by a balance between the rate of

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ionization and the rate of recombination. Since the power output of a MHD generator is proportional to the electrical conductivity, an enhancement of the electrical conductivity may result in an enhancement of the power output.

The possibility of using the energy released by neutron-absorption processes in ^{3}He to enhance electrical conductivity for MHD energy-conversion purposes was first seriously considered by a group led by J. Braun at AB Atomenergi in Sweden from the early 1960's to the mid-1970's [1]. The group measured the conductivity of ^{3}He for temperatures from 300 K to 1600 K and bulk densities from 0.25 to 1.0 standard atmospheric density with neutron flux less than 10^{11} /cm^{2}s. They concluded that for the limited range of conditions considered, the enhancement of the conductivity was insufficient to be of use for MHD energy conversion [2]. The Braun experiments remain to date the most extensive study of conductivity enhancement in ^{3}He by neutron interaction. This conclusion would seem to discourage further study of the concept; however, new calculations show there may exist a large region of thermodynamic and neutron flux conditions that may result in significant conductivity enhancement. The results of these calculations are shown graphically in Figure 1.

The objective of this project was to provide a conclusive data set describing the degree of nuclear-induced electrical conductivity in ^{3}He over a wide range of thermodynamic and reactor conditions. Specifically, the range of conditions being studied are: gas density from 10^{-4} to 1 standard atmospheric density, gas temperature from 300 K to 1500 K, and neutron flux from 10^{10} /cm^{2}s to 10^{16} /cm^{2}s. The goal of these experiments was to confirm the calculated behavior of the induced conductivity and provide baseline data for future design studies of nuclear-driven MHD energy-conversion systems over an appropriately wide range of conditions.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in nuclear science, plasmas, and beams as well as complex experimentation and measurement. As the largest consumer of energy in the world, the United States has a continuous interest in the development of more efficient means of energy conversion. As environmental concerns become more significant, the Nation's energy sources are being subjected to ever greater scrutiny. Nuclear-driven MHD energy conversion offers the potential of a highly efficient cycle (typically greater than 55% efficiency) with little or no emissions into the environment while also being more reliable due to the elimination of moving parts. Los Alamos National Laboratory has a reputation for originating and developing advances in nuclear cycle technologies.

3. Scientific Approach and Results to Date

To accomplish the goals stated above, a static gas chamber was designed and constructed. The chamber has been designed to maintain a gas volume 20 cm long by 20 cm in diameter at a specific temperature and density over the range of conditions being studied. Since the experiments are being carried out at the Pennsylvania State Breazeale Reactor Facility, water tight access ports were incorporated into the apparatus for instrumentation, power, and gas supplies to the chamber, which is operated in the reactor pool (see Figure 2).

Figure 3 shows a cross section of the chamber assembly with the access ports removed. As shown in the figure, the gas volume is surrounded by a cylindrical heater capable of temperatures in excess of 1500K. The heater and gas-volume ends are surrounded by 5 inches of alumina insulation and a stainless-steel outer shell that is vacuum tight. When operating at full temperature, the stainless-steel shell remains cool enough to be touched with the bare hand.

In Figure 3, the locations of the various instrumentation probes are also shown. The only exceptions are the two thermocouple gauges used to monitor the gas temperature, which are located above and below the plane of the cross section. Two types of probes are used to collect the conductivity data. The primary method uses the center electrode and gas-volume shell in conjunction with the two floating field probes. This method utilizes a form of Ohm's Law to measure directly the average electrical conductivity of the gas [**2**]. The second method utilizes the triple probe to collect electron-density and temperature data for comparison with the conductivity probe data.

The experimental apparatus has been constructed, assembled, and tested. In the process of testing the system, some unexpected operational problems were discovered. The two primary problems involved outgassing from the insulating material and difficulties with the internal assembly and disassembly. The outgassing problem was remedied by a change in procedures, namely, all of the insulating components being prefired, which permanently eliminates all outgassing species. The difficulties with internal assembly were corrected by minor redesign of a few components. These changes are reflected in Figure 3. As a result of these design changes, the system as a whole is easier to operate, more flexible, and should provide more accurate data.

References

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2. Braun, J., K. Nygaard, "Measurement of the Electrical Conductivity of ^{3}He Plasma Induced by Neutron Irradiation," AE-218, AB Atomenergi, Sweden, 1966.

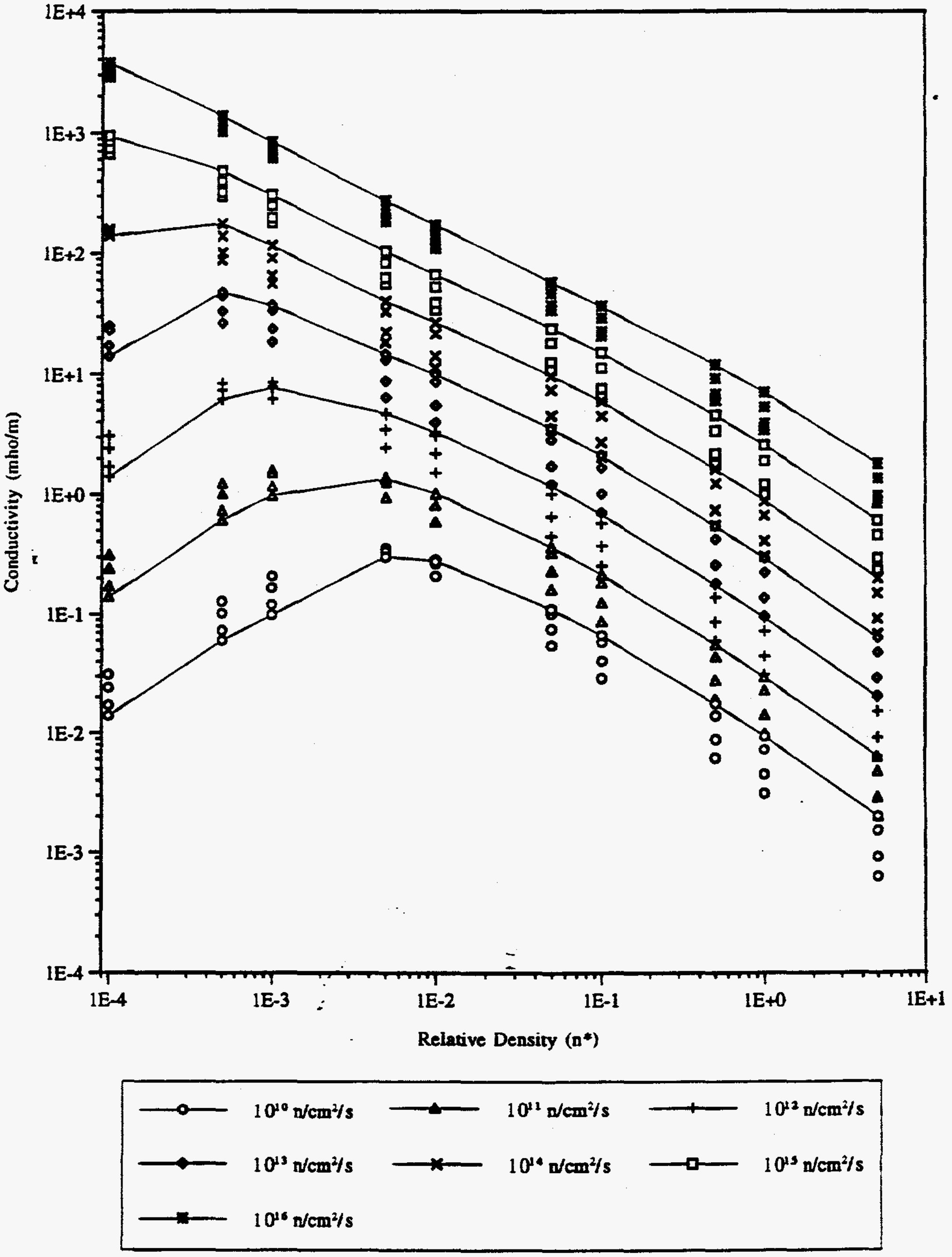


Figure 1. Electrical conductivity versus gas density for pure ^{3}He as a function of gas temperature and neutron flux. Data was calculated using CSOLVE code modeling an infinite volume.

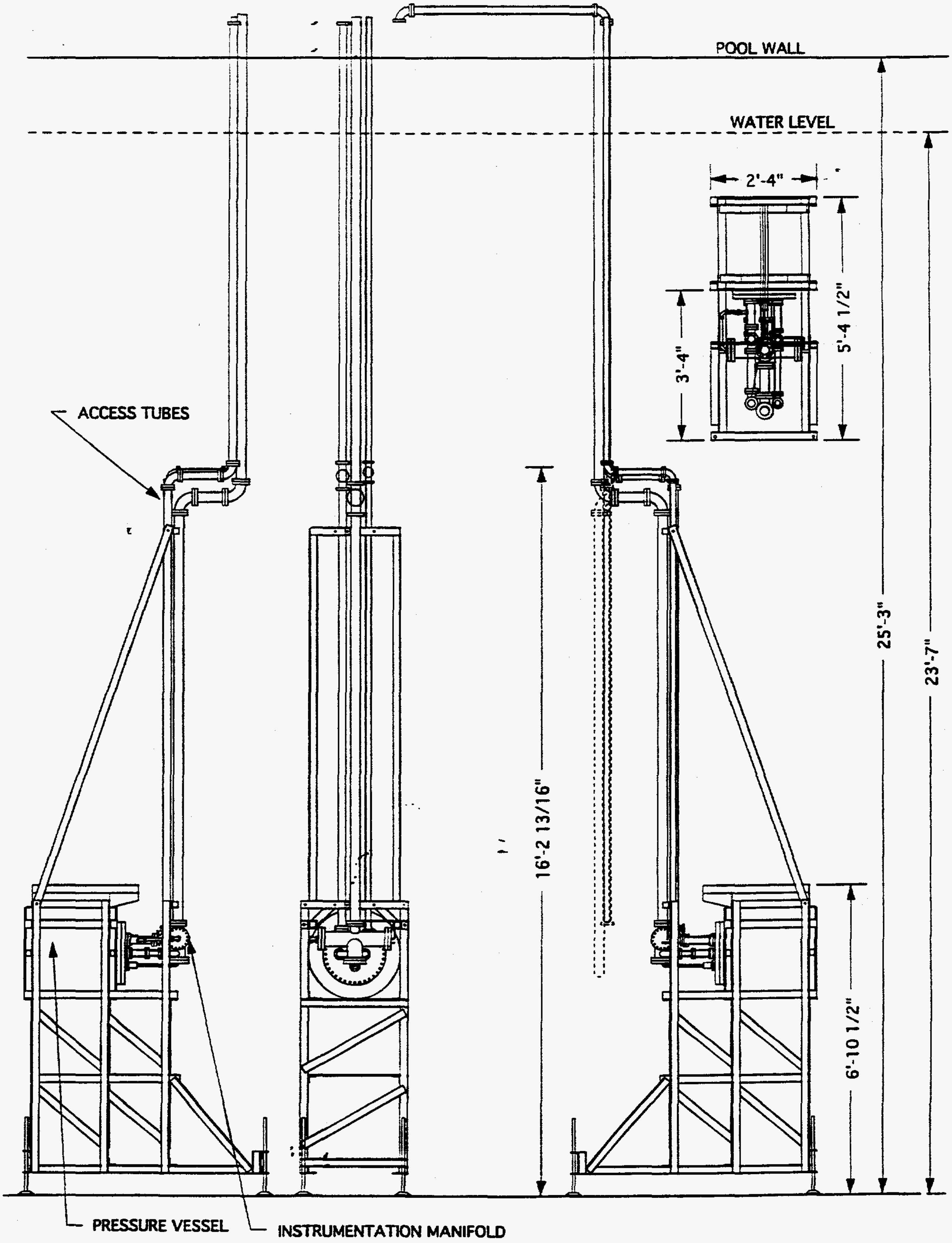
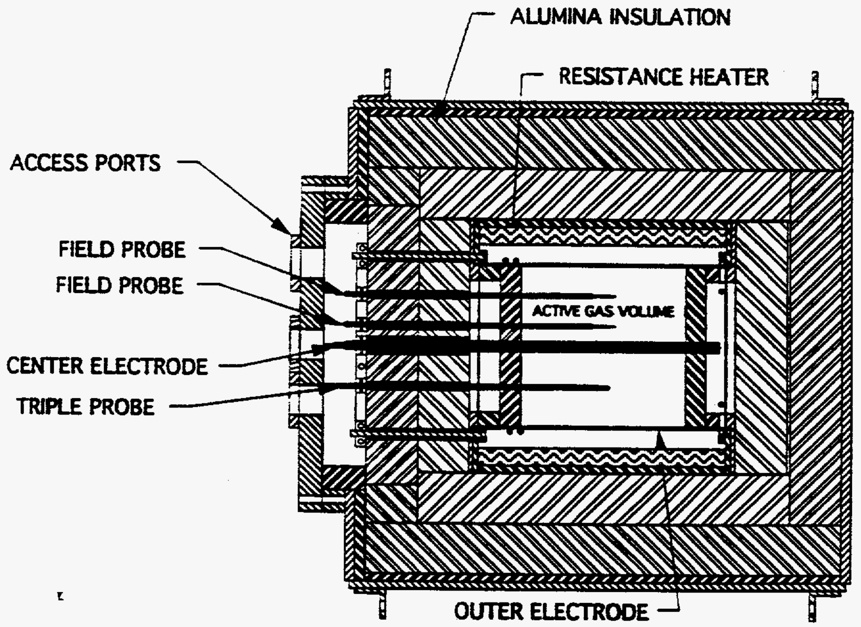
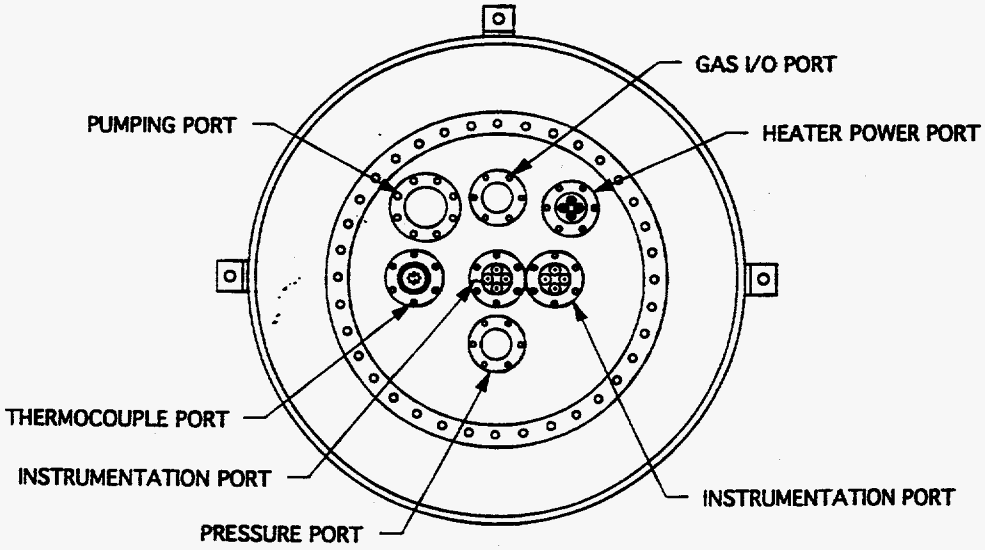


Figure 2. Apparatus assembly drawing showing multiple views and configuration in reactor pool.



CHAMBER CROSS SECTION



CHAMBER END VIEW

Figure 3. Cross-section and end view of pressure vessel.